A standard model explanation of a CDF dijet excess in Wjj

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We demonstrate the recent observation of a peak in the dijet invariant mass of the Wjj signal observed by the CDF Collaboration can be explained as the same upward fluctuation observed by CDF in single-top-quark production. In general, both t-channel and s-channel single-top-quark production produce kinematically induced peaks in the dijet spectrum. Since CDF used a Monte Carlo simulation to subtract the single-top backgrounds instead of data, a peak in the dijet spectrum is expected. The DØ Collaboration has a small upward fluctuation in their published t-channel data; and hence we predict they would see at most a small peak in the dijet invariant mass spectrum of Wjj if they follow the same procedure as CDF.

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The recent observation by CDF of a large peak in the background-subtracted dijet spectrum of Wjj has caused significant excitement about a possible observation of beyond the standard model physics [1]. The key question is whether this excess is an artifact of the procedure used to subtract the standard model background. There are large excesses in a few exclusive channels of the CDF single-top-quark data set [2] that can explain most, or possibly all, of the peak in the Wjj data. Hence there are two possibilities: there is evidence of unexpected signals in multiple CDF measurements, or there is an upward fluctuation in single-top-quark production with respect to Monte Carlo that simply appears to be new physics. Given the good agreement between the standard model prediction and the DØ data set for single-top-quark production [3], we focus on the latter case.

We first point out that events involving top-quark production generically produce a peak in a dijet spectrum. In the top-quark rest frame, the b in $t \to bW$ has an energy of $\sim$ 70 GeV. Hence, there is a peak just below that energy in the transverse energy E_T spectrum. When combined with any other jet, where a jet is defined as having E_T greater than some threshold, the dijet invariant mass has a peak above $E_{Tb} + E_{Tj}$. This means that any analysis that finds a peak in the dijet spectrum in the 100–160 GeV range will be sensitive to how well the top-quark backgrounds are removed. The CDF analysis claims to have normalized the $t\bar{t}$ background to data, but removed the single-top-quark backgrounds via Monte Carlo. Thus, we focus on single-top-quark production within the CDF data set.

In order to convert the measurement of single-top-quark production into a prediction for Wjj, we start with the CDF single-top-quark analysis [2]. This analysis was performed with the same lepton trigger and a 3.2 fb^{-1} subset of the 4.3 fb^{-1} data used for the Wjj analysis. We fit the cross sections observed by CDF in four channels: Wbj, $Wbjj$, Wbb, and $Wbbj$ to a K-factor times the next-to-leading order predictions from Ref. [4] for the exclusive final states. In order to account for cross-contamination in the 1-tag and 2-tag samples we assume a 50% average b-tagging efficiency. In Table I we show the extracted K-factors with experimental errors. Additional theoretical uncertainties are discussed below.

TABLE I: K-factors for t-channel and s-channel single-top-quark exclusive final states extracted from fits to CDF data [2] and the NLO predictions of Ref. [4]. Uncertainties correspond to 1σ fluctuations in the CDF analysis.

Process	Wbj	Wbb	$Wbjj$	$Wbbj$
t-chan.	$0.6^{+0.3}_{-0.2}$	$0.4^{+0.2}_{-0.2}$	$0.9^{+0.8}_{-0.7}$	$2.0^{+1.5}_{-1.3}$
s-chan.	$0.5^{+0.2}_{-0.1}$	$3.8^{+2.1}_{-1.7}$	$0.6^{+0.5}_{-0.4}$	$2.7^{+2.1}_{-1.8}$

It is interesting to note, the CDF extraction of the t-channel cross section has a K-factor of 0.5 when averaging the Wbj and Wbb samples. Hence, one might expect that subtracting the Monte Carlo prediction from the data would lead to a deficit rather than an excess in the dijet data. However, the $Wbbj$ contribution to the t-channel cross section has an excess of a factor of 2–3.5. In the current Wjj exclusive final state, the cuts on the jets are raised from $E_{Tj} > 20$ GeV to $E_{Tj} > 30$ GeV. As mentioned in Ref. [4], this converts a significant fraction of 3-jet events from the single-top-quark sample to 2-jet events. This is demonstrated in Fig. 1, where the area above 20 GeV is similar to the area below 30 GeV in the distribution of the initial-state radiated b-jet in t-channel production, which is typically the third jet in the event. It is critical to remember that the distribution of that b-jet is only known to leading order (LO), and is afflicted by the same large logarithms that enhance the t-channel cross section. Hence, when a sharp cut is applied to the data, the uncertainty in the normalization of the exclusive 2-jet state is nearly a factor of 2.

In addition to the measured excess, there are possible enhancements to the exclusive 2-jet cross section due to other cuts on the data. One very sensitive cut is on the missing transverse energy $\not{E}_T > 25$ GeV. Lowering the $\not{E}_T$ threshold in the theoretical prediction by 5 GeV

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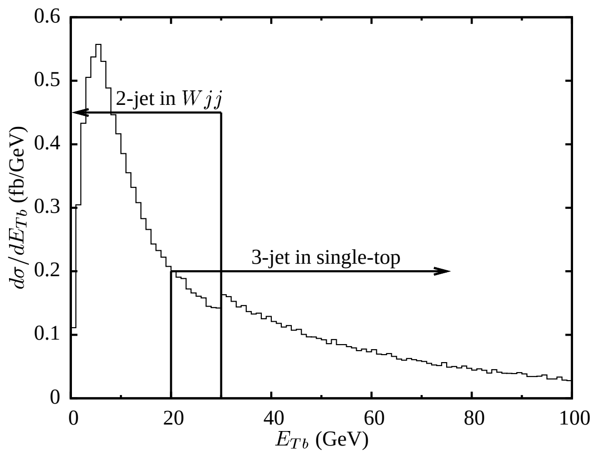

FIG. 1: Transverse energy spectrum of the additional b-jet in t-channel single-top-quark production. A 3-jet excess in single-top (where $E_{Tj_3} > 20$ GeV) is converted to a 2-jet excess in Wjj (where $E_{Tj_3} < 30$).

changes the predicted single-top acceptance by $\sim 50\%$. A 5 GeV shift is easily accommodated by the $\not\!\!E_T$ resolution, and the fact that there are 1–2 b hadrons in the final state. These b's decay to neutrinos that add to the $\not\!\!E_T$. In addition, the initial-state radiation jets in single-top are frequently in less-well instrumented regions of the detector and contribute to $\not\!\!E_T$. All of these effects enter in the same direction to enhance the predicted cross section.

One visually striking feature of the CDF excess is the apparent peak between 120–160 GeV. If not for the low bin around 112 GeV, the excess would go down to 96 GeV. A direct scaling of CDF single-top data would cover both this broader region and below. However, the position of the peak is very sensitive to the jet energy scale. There is a 25% absolute correction times an additional 10% out-of-cone correction for the measured jet energies [5]. These large corrections lead to a 16% systematic uncertainty in the jet energy scale [2]. If some of the jets are b jets, then the uncertainty may be larger. The consequence is that the predicted position of the dijet invariant-mass peak M_{jj} can shift higher toward the position of the CDF excess.

If the energy scale of the jets shifts upward, additional jets that would have failed the dijet system transverse momentum cut $p_{Tjj} > 40$ GeV cut will now pass. The theoretical prediction for the p_{Tjj} spectrum is very sensitive to the cut chosen in the CDF analysis. It is important to remember that the p_{Tjj} distribution is only predicted at leading order. As in Drell-Yan production, resummation of initial-state radiation will slightly harden this spectrum. The dijet system will also recoil against any third jet that passes the acceptance cut. We estimate from our 3-jet samples that these corrections can accommodate a 10–20 GeV upward shift in the p_{Tjj} spectrum. A 10 GeV shift would increase the background acceptance by $\sim 50\%$.

One may wonder whether there is a large excess in the 2 b-tag CDF dijet invariant mass. CDF has measured that signal in an analysis to search for Higgs production in $WH \to Wb\bar{b}$ [6]. There are two reasons we do not expect to see a large excess in that study. First, the deficit in Wbb from t-channel single-top is almost perfectly cancelled by the excess in the s-channel single-top contribution. The basic cuts in the Higgs analysis are almost identical to the single-top-quark analysis, and so there is no contamination from processes with additional jets. Furthermore, in the CDF Higgs analysis, they normalize their background subtraction to data. Hence, any residual excess should be removed.

When we include the error in the *prediction* of $\not\!\!E_T$ and jet energy scale, we find that it is possible to reproduce the excess distribution up to binning effects. In Fig. 2 we superimpose on the CDF data a prediction obtained by boosting $\not\!\!E_T$ by 16%, increasing the jet energy scale by 10%, and mixing 3.5 times the t-channel ($Wbbj$) background contribution to the 2-jet sample, -0.5 times the t-channel (Wbj) contribution, and 5 times the s-channel signal. This combination corresponds to slightly less than a 1σ fluctuation of the total single-top background from CDF data minus 1 times the standard model theoretical prediction. Our net prediction (solid black histogram) for the residual single-top-quark contribution to M_{jj} reproduces the both the excess between 120–160, and the excess on the right shoulder of the WW/WZ fit. The modeling uncertainty in the normalization of this curve is about a factor of 2.

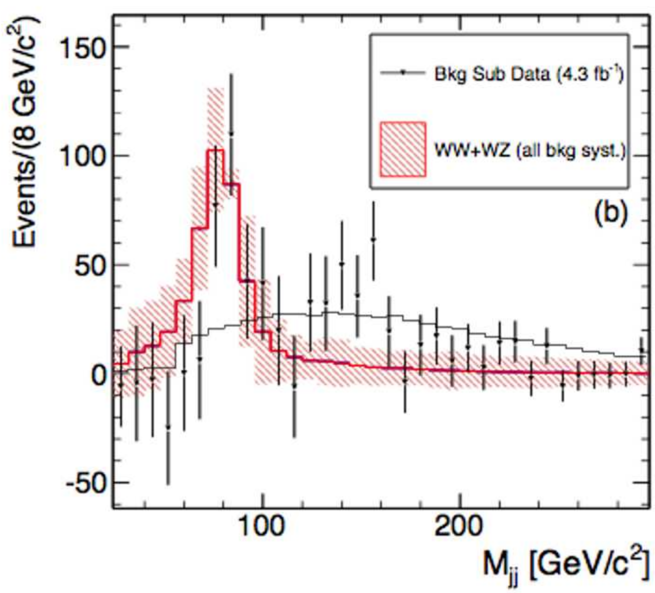

FIG. 2: Prediction of the single-top-quark excess (solid black line) remaining in the dijet invariant mass M_{jj} in Wjj after subtracting 1× the standard model prediction from the CDF single-top-quark data [2]. Wjj data from Ref. [1].

In conclusion, we observe that the dijet invariant mass peak seen in the recent CDF Wjj cross section [1] is completely consistent with the excess observed in the CDF

single-top-quark analysis [2]. Both may be explained by an upward fluctuation in the CDF data set of s-channel single-top-quark production, and t-channel production accompanied by an additional low-energy jet. The latter process is poorly modeled by Monte Carlo, and the apparent t-channel excess could simply be an artifact of theoretical uncertainty. Given the modest excess observed by the DØ Collaboration in their single-top-quark data set [3], we predict the DØ Collaboration would not see a significant dijet invariant mass peak if they follow the CDF procedure.

Acknowledgments

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